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# The 2014 PV Performance Modeling Workshop: Welcome and Purpose

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# 2014 PV Systems Symposium

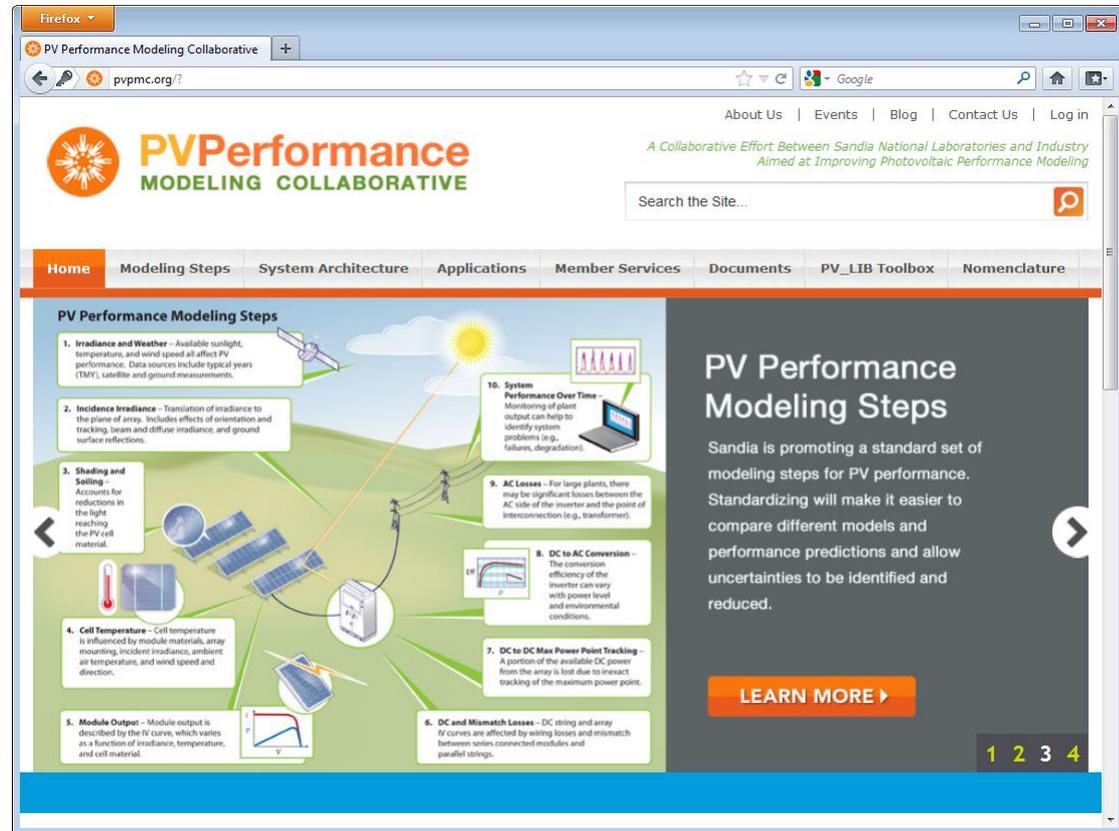
- Sandia National Laboratories and the Electric Power Research Institute decided in 2013 to collectively host a series of workshops on solar PV systems topics.
  
- 2014 PV Systems Symposium Events
  - **May 5: PV Performance Modeling Workshop**
  - May 6: PV Distribution Modeling Workshop (Breakfast at 7AM)
  - May 7: PV Operations and Maintenance Workshop (EPRI Headquarters)
  - May 7: EPRI Smart Inverter Workshop (Biltmore)
  - May 8: ASTM International subcommittee E44.09 Photovoltaic Electric Power Conversion (EPRI Headquarters)

# PV Performance Modeling Collaborative Sandia National Laboratories

- Started after 1st PV Performance Modeling Workshop (Albuquerque, NM, Sept. 2010)
- PV performance modeling lacked organization.
  - Accurate information about algorithms, validation data, best practices difficult to find and access.
- PVPMC.org started to provide an information hub on PV performance modeling
  - Model agnostic, focus on algorithms, methods, data, etc.
  - Detailed Modeling Steps (online textbook)
  - Modeling function library in Matlab **and Python** (PV\_LIB)
  - Member contact list, document library, bibliography, glossary, blog, events, ...
- 2<sup>nd</sup> PV Performance Modeling Workshop (Santa Clara, CA, May 2013)

# Website: <http://pvpmc.org>

- 1330 Members (and growing)
- 10,000 to 15,000 visits per month
- 218 web pages published



The screenshot shows the website for the PV Performance Modeling Collaborative. The browser window is titled "PV Performance Modeling Collaborative" and the address bar shows "pvpmc.org?". The website features a navigation menu with items like Home, Modeling Steps, System Architecture, Applications, Member Services, Documents, PV\_LIB Toolbox, and Nomenclature. The main content area is titled "PV Performance Modeling Steps" and includes a diagram of a solar panel system with numbered callouts (1-10) explaining various modeling factors such as Irradiance and Weather, Incidence Irradiance, Shading and Soiling, Cell Temperature, Module Output, DC and Mismatch Losses, DC to AC Conversion, DC to DC Max Power Point Tracking, AC Losses, and System Performance Over Time. A sidebar on the right contains the text "PV Performance Modeling Steps" and "Sandia is promoting a standard set of modeling steps for PV performance. Standardizing will make it easier to compare different models and performance predictions and allow uncertainties to be identified and reduced." Below this text is a "LEARN MORE" button and a page indicator showing "1 2 3 4".

When you join you will set up a *username* and *password*  
-Sign up for weekly email updates separately

# PV Performance Modeling Steps

**1. Irradiance and Weather** – Available sunlight, temperature, and wind speed all affect PV performance. Data sources include typical years (TMY), satellite and ground measurements.



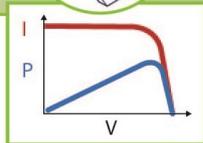
**2. Incidence Irradiance** – Translation of irradiance to the plane of array. Includes effects of orientation and tracking, beam and diffuse irradiance, and ground surface reflections.

**3. Shading and Soiling** – Accounts for reductions in the light reaching the PV cell material.

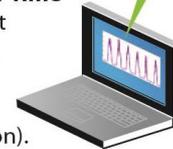
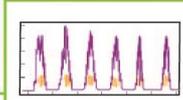


**4. Cell Temperature** – Cell temperature is influenced by module materials, array mounting, incident irradiance, ambient air temperature, and wind speed and direction.

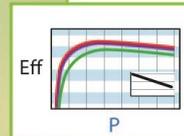
**5. Module Output** – Module output is described by the IV curve, which varies as a function of irradiance, temperature, and cell material.



**10. System Performance Over Time** – Monitoring of plant output can help to identify system problems (e.g., failures, degradation).



**9. AC Losses** – For large plants, there may be significant losses between the AC side of the inverter and the point of interconnection (e.g., transformer).



**8. DC to AC Conversion** – The conversion efficiency of the inverter can vary with power level and environmental conditions.

**7. DC to DC Max Power Point Tracking** – A portion of the available DC power from the array is lost due to inexact tracking of the maximum power point.

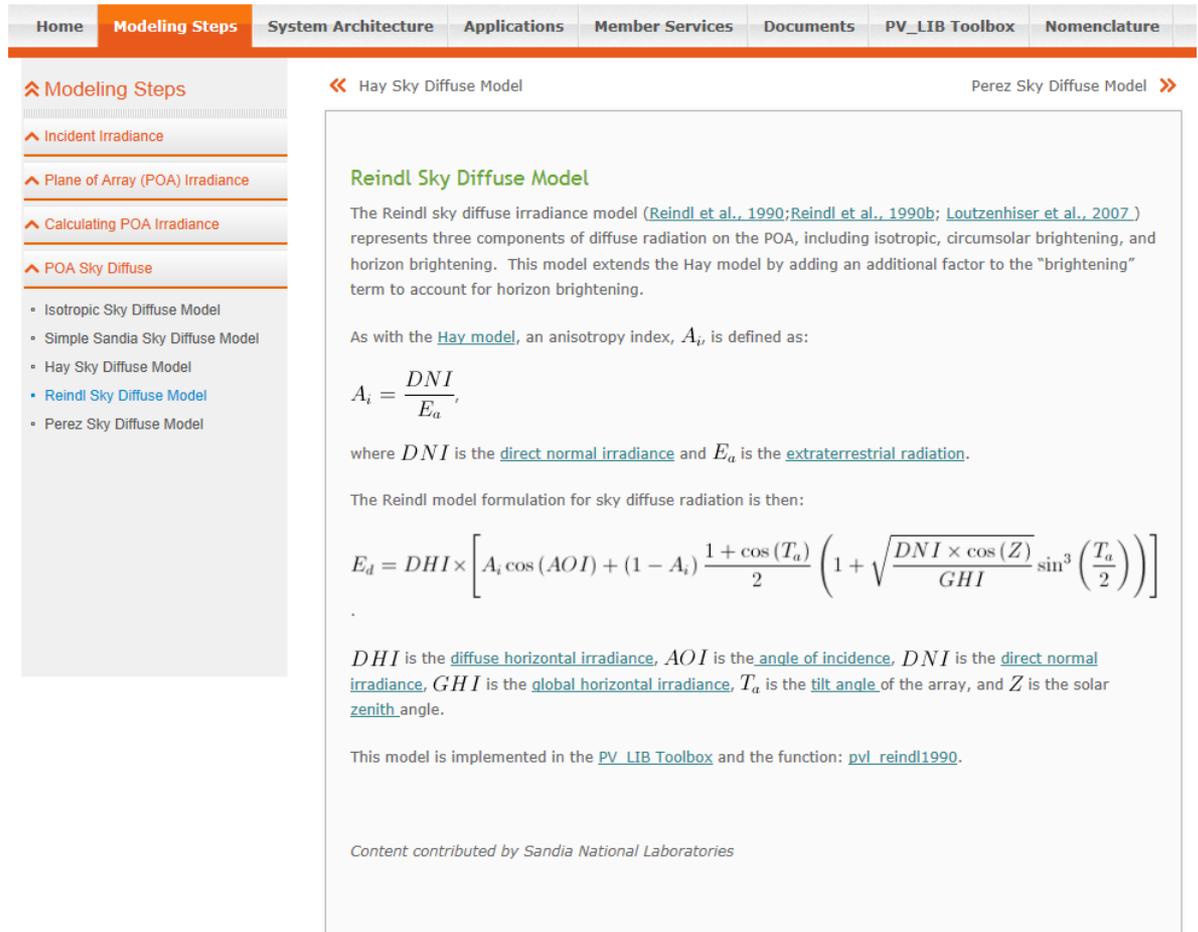
**6. DC and Mismatch Losses** – DC string and array IV curves are affected by wiring losses and mismatch between series connected modules and parallel strings.

# Standard Modeling Steps

- Irradiance and Weather
  - Definitions and Overview
  - Sun Position
    - [Solar Position Algorithm \(SPA\)](#)
    - [Simple models](#)
    - [Sandia's code](#)
  - Irradiance and Insolation
    - [Extraterrestrial radiation](#)
    - [Air Mass](#)
    - [Direct Normal Irradiance](#)
      - [DSC Model](#)
      - [DIRINT Model](#)
    - [Global Horizontal Irradiance](#)
    - [Diffuse Horizontal Irradiance](#)
    - [Spectral Content](#)
      - [AM 1.5 Standard Spectrum](#)
    - [Satellite derived data](#)
  - Weather Observations
    - [Air Temperature](#)
    - [Wind Speed and Direction](#)
    - [Precipitation](#)
    - [Air Pressure](#)
  - Irradiance Data Sources for Performance Modeling
    - [National Solar Radiation Database](#)
    - [Typical Meteorological Years](#)
    - [Site-Specific Data](#)
    - [Measure Correlate Predict](#)
    - [Irradiance Modeling](#)
  - Uncertainty and Variability
    - [Characterization of Irradiance Variability](#)
      - [Interannual variability](#)
      - [Short-term variability](#)
      - [Spatial variability](#)
    - [Clear Sky Irradiance models](#)
- Incident Irradiance
  - Definitions and Overview
  - Array Orientation
    - [Fixed tilt](#)
    - [Single Axis Tracking](#)
      - [1-Axis Horizontal Roll](#)
      - [1-Axis Tilted Roll](#)
      - [1-Axis Equatorial](#)
    - [Two-Axis Tracking](#)
      - [2-Axis Azimuth-Elevation](#)
      - [2-Axis Polar](#)
      - [2-Axis Tilt-Roll](#)
    - [Array Orientation Errors](#)
      - [Effect of Array Tilt Errors](#)
      - [Effect of Array Azimuth Errors](#)
  - Plane of Array (POA) Irradiance
    - [Measuring POA Irradiance](#)
    - [Calculating POA Irradiance](#)
      - [POA Beam](#)
      - [Angle of Incidence](#)
      - [POA Ground Reflected](#)
        - [Albedo](#)
      - [POA Sky Diffuse](#)
- Shading, Soiling, and Reflection Losses
  - Definitions and Overview
  - Shading
    - [Far Shading](#)
    - [Near Shading](#)
  - Soiling and Snow
    - [Soil Monitoring Studies](#)
    - [Snow Effects](#)
  - Incident Angle Reflection Losses
    - [Physical Model of IAM](#)
    - [ASHRAE Model](#)
    - [Martin and Ruiz IAM Model](#)
    - [Sandia Model](#)
      - [Soiling effects on Incident Angle Losses](#)
- Cell Temperature
  - Definitions and Overview
  - Module Temperature
    - [Thermocouple](#)
    - [Voc method](#)
    - [Sandia Module Temperature Model](#)
    - [Faiman Module Temperature Model](#)
  - Cell temperature
    - [Sandia Cell Temperature Model](#)
    - [PVsyst Cell Temperature Model](#)
    - [Transient Cell Temperature Models](#)
- Module IV Curve
  - Definitions and Overview
  - Effective Irradiance
    - [Spectral Mismatch](#)
  - Single Diode Equivalent Circuit Models
    - [De Soto "Five-Parameter" Module Model](#)
    - [PVsyst Module Model](#)
  - Point-value models
    - [Sandia PV Array Performance Model](#)
    - [Loss Factor Model](#)
    - [PVWatts](#)
      - [Improvements to PVWatts](#)
- DC and Mismatch Losses
  - Definitions and Overview
  - Module IV Curves
  - String IV Curves
    - [String Mismatch Losses](#)
  - Array IV Curves
    - [Array Mismatch Losses](#)
  - DC Wiring Losses
- Maximum Power Point Tracking
  - Definitions and Overview
  - [Array Utilization](#)
  - [MPPT Voltage](#)
  - [MPPT Efficiency](#)
  - [MPPT Algorithms](#)
  - [Uncertainty and Validation](#)
- DC to AC Conversion
  - Definitions and Overview
  - Inverter Efficiency
    - [CEC Inverter Test Protocol](#)
    - [Operating Temperature](#)
    - [Sandia Inverter Model](#)
    - [Dresse Inverter Model](#)
  - [Inverter Saturation](#)
  - [Loss of Grid](#)
  - [Advanced Inverter Features](#)
    - [Power Factor Control](#)
  - [Uncertainty and Validation](#)
- AC Losses
  - Definitions and Overview
  - [AC Wiring Losses](#)
  - [Transformer Losses](#)
- PV System Output
  - Definitions and Overview
  - PV System Monitoring
    - [Monitoring Equipment](#)
    - [Data Filtering](#)
    - [Data Filling](#)
  - PV Performance Metrics
    - [Performance Ratio](#)
    - [Performance Index](#)
    - [Annual Yield](#)
  - PV Systems Operations and Maintenance
    - [Definitions and Overview](#)
    - [Availability](#)
    - [Failure Mode and Rates](#)
- References
- Uncertainty and Validation Studies

# Example Model Description

- Brief description
- Equation support
- Hyperlinking
- Link to PV\_LIB functions
- References
- Contributor info
  
- We are looking for additional models and process descriptions



The screenshot shows the PVPerformance website interface. The top navigation bar includes links for Home, Modeling Steps, System Architecture, Applications, Member Services, Documents, PV\_LIB Toolbox, and Nomenclature. The left sidebar lists the Modeling Steps hierarchy: Incident Irradiance, Plane of Array (POA) Irradiance, Calculating POA Irradiance, and POA Sky Diffuse. Under POA Sky Diffuse, several models are listed, with the Reindl Sky Diffuse Model selected. The main content area displays the Reindl Sky Diffuse Model page, which includes a description of the model, its components, and the mathematical formulation for sky diffuse radiation. The page also mentions that the model is implemented in the PV\_LIB Toolbox.

Home | **Modeling Steps** | System Architecture | Applications | Member Services | Documents | PV\_LIB Toolbox | Nomenclature

Modeling Steps

- Incident Irradiance
- Plane of Array (POA) Irradiance
- Calculating POA Irradiance
- POA Sky Diffuse
  - Isotropic Sky Diffuse Model
  - Simple Sandia Sky Diffuse Model
  - Hay Sky Diffuse Model
  - Reindl Sky Diffuse Model**
  - Perez Sky Diffuse Model

Hay Sky Diffuse Model | Perez Sky Diffuse Model

### Reindl Sky Diffuse Model

The Reindl sky diffuse irradiance model (Reindl et al., 1990; Reindl et al., 1990b; Loutzenhiser et al., 2007) represents three components of diffuse radiation on the POA, including isotropic, circumsolar brightening, and horizon brightening. This model extends the Hay model by adding an additional factor to the "brightening" term to account for horizon brightening.

As with the Hay model, an anisotropy index,  $A_i$ , is defined as:

$$A_i = \frac{DNI}{E_a}$$

where  $DNI$  is the direct normal irradiance and  $E_a$  is the extraterrestrial radiation.

The Reindl model formulation for sky diffuse radiation is then:

$$E_d = DHI \times \left[ A_i \cos(AOI) + (1 - A_i) \frac{1 + \cos(T_a)}{2} \left( 1 + \sqrt{\frac{DNI \times \cos(Z)}{GHI}} \sin^3\left(\frac{T_a}{2}\right) \right) \right]$$

$DHI$  is the diffuse horizontal irradiance,  $AOI$  is the angle of incidence,  $DNI$  is the direct normal irradiance,  $GHI$  is the global horizontal irradiance,  $T_a$  is the tilt angle of the array, and  $Z$  is the solar zenith angle.

This model is implemented in the PV\_LIB Toolbox and the function: `pvl_reindl1990`.

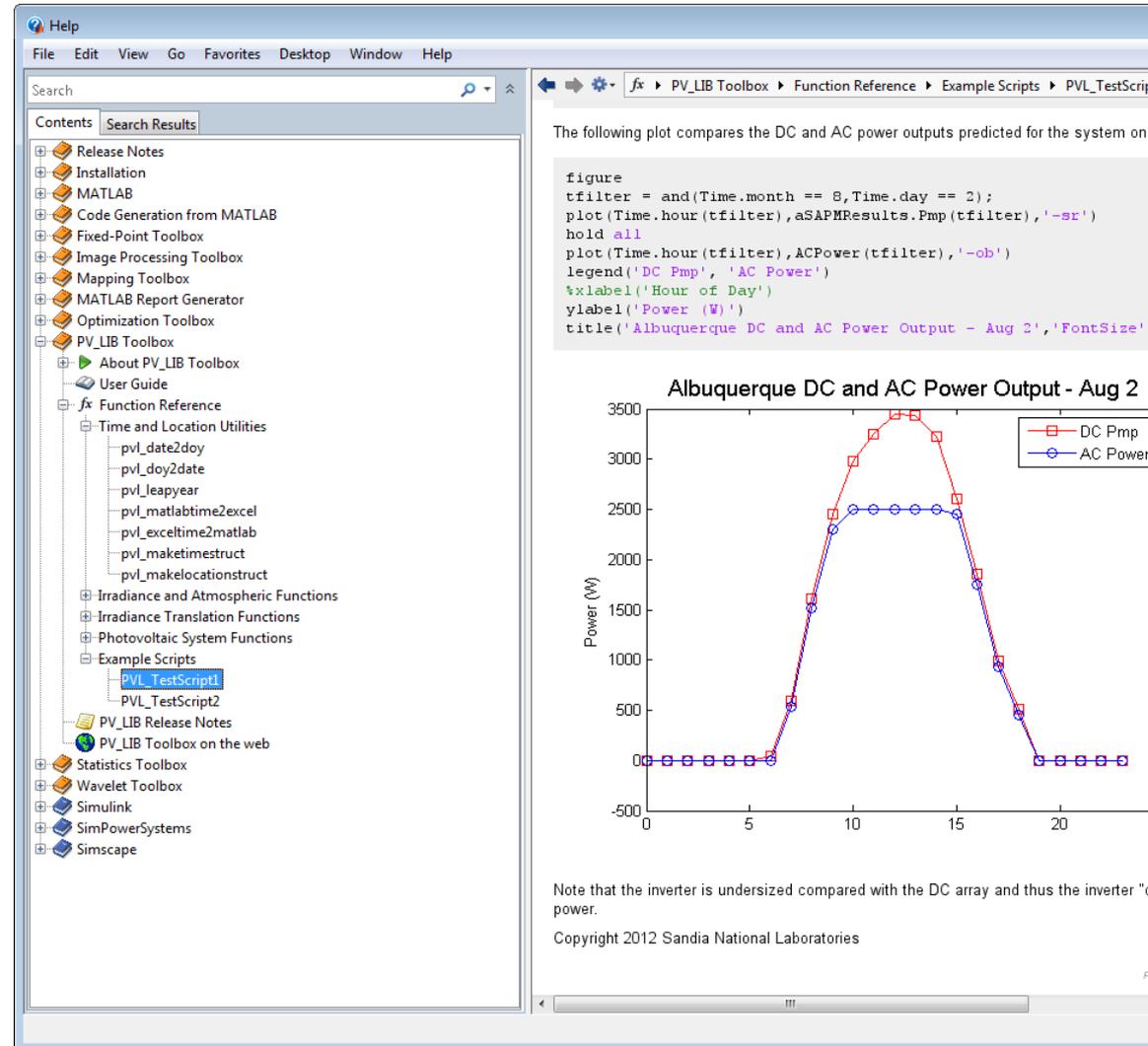
Content contributed by Sandia National Laboratories

# Modeling Steps: Areas Needed for Contributions

- Tracking, backtracking models
- Shading models and effect on performance
- Soiling (and cleaning) models
- Module IV parameter estimation methods
- Degradation models / processes
- MPPT algorithms
- Monitoring standards
- System Architecture (component and design descriptions)
- Applications (model reviews, features, case studies, validation)
- Much more.....

# PV\_LIB Toolbox for Matlab and Python!

- Over 30 functions
  - Example scripts
  - Time and Location Utilities
  - Irradiance and atmospheric functions
  - Irradiance translation functions
  - Photovoltaic system functions
- Education, model validation, transparency



# New Features Coming Soon!

- Website is being redesigned in 2014
  - Adding ability for members to contribute content directly (moderated)
    - Create/edit web pages
    - Upload documents and reports
- PV\_LIB for Python will be released this summer.
  - Python is free

# 2014 Workshop Program

- *8:15 - 10:05 AM*: Solar Resource (Measurements and Datasets)
- *10:30 - 1:20 PM*: Measuring Module Performance
- *1:35 - 2:50 PM*: Optimizing Design with PV Performance Models
- *3:20- 5 PM*: Inverter Performance Models
- *5:30-6:30 PM*: Buffet Dinner offered by Biltmore (\$20?)
- *7-9 PM*: Special Evening (“Traffic Buster”) Session on Modeling Tool Updates
  
- Networking Breaks are longer this year by request!

# Thank You!

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<http://solar.sandia.gov>

<http://PV.sandia.gov>

<http://pvpmc.org>

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